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MISSOURI S&T
Smart Engineering Systems Lab
Engineering Management and Systems Engineering Department

Flexible and Intelligent Learning Architectures for SoS
FILA-SoS

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FILA-SoS Highlights

FILA-SoS and the Wave Process address four of the most challenging aspects of system-of-system architecting:

1.) Dealing with the uncertainty and variability of the capabilities and availability of potential component systems.

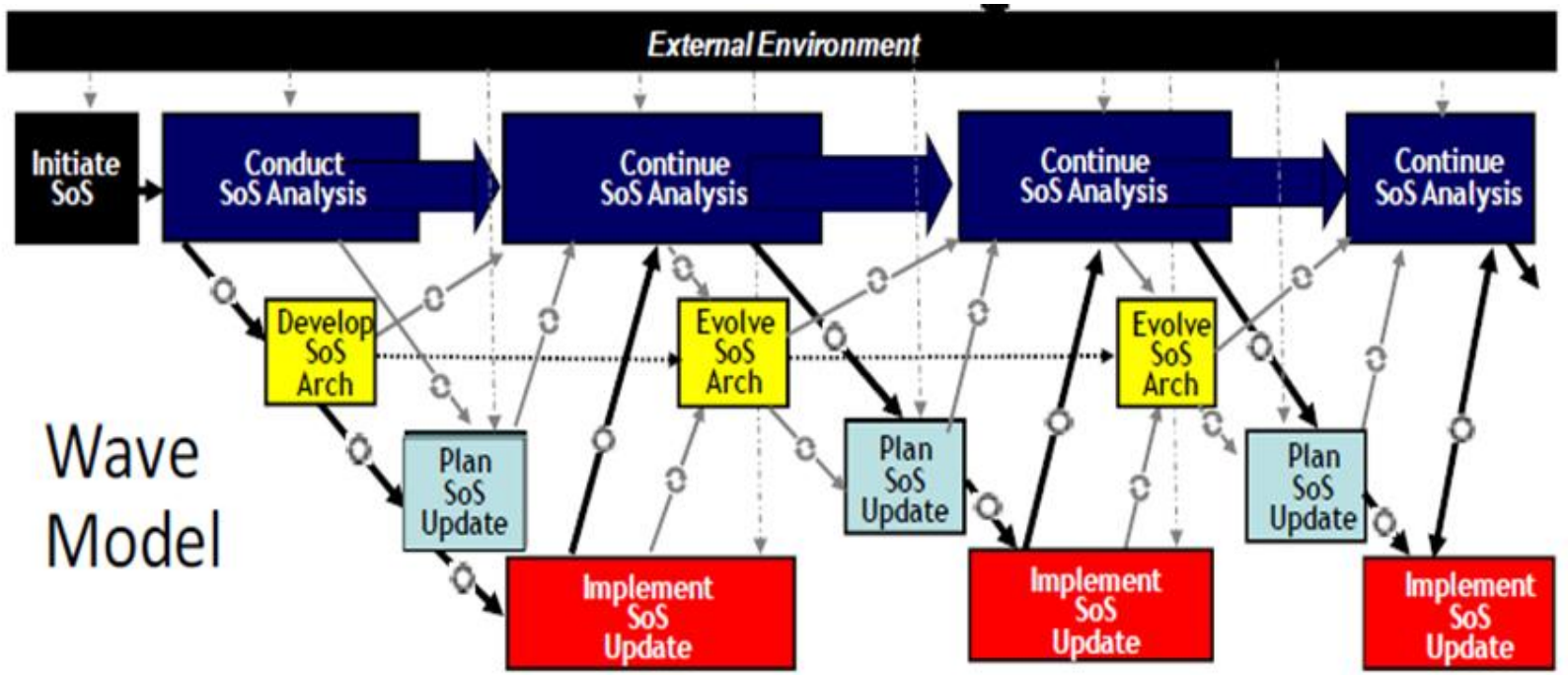
2.) Providing for the evolution of the system-of-system needs, resources and environment over time.

3.) Accounting for the differing approaches and motivations of the autonomous component system managers.

4.) Optimizing system-of-systems characteristics in an uncertain and dynamic environment with fixed budget and resources

FILA-SoS does so using straightforward system definitions methodology and an efficient analysis framework that supports the exploration and understanding of the key trade-offs and requirements by a wide range system-of-system stakeholders and decision makers in a short time.

The Wave Model of SoS



The Wave Model of SoS initiation, engineering, and evolution

Wave Process and FILA-SoS

Initialize SoS

- Wave process: Understand the SoS objectives and operational concept (CONOPS), gather information on core systems to support desired capabilities
- FILA-SoS: Enter Input values required to run the FILA-SoS which include the number of negotiation cycles, meta-architecture generation model selection type and individual system negotiation model types

Conduct_SoS_Analysis

- Wave process: Establish an initial SoS baseline architecture for SoS engineering based on SoS requirements space, performance measures, and relevant planning elements
- FILA-SoS: Execute the meta-architecture generation model which selects an initial SoS baseline architecture using the given input data

Develop/ Evolve SOS

- Wave process: Identify the necessary changes in contributing systems in terms of interfaces and functionality in order to implement the SoS architecture
- FILA-SoS: Send connectivity request to individual systems and start the negotiation between SoS and individual systems

Plan SoS Update /

- Wave process: Plan for the next SoS upgrade cycle based on the changes in external environment, SoS priorities, options and backlogs
- FILA-SoS: Determine which systems to include based on the negotiation outcomes and form a new SoS architecture

Implement SoS Architecture

- Wave process: Establish a new SoS baseline based on SoS level testing and system level implementation
- FILA-SoS: Evaluate the negotiated architecture quality and decide to renegotiate or move on to the next acquisition wave

SoS Behavior Object Process Model

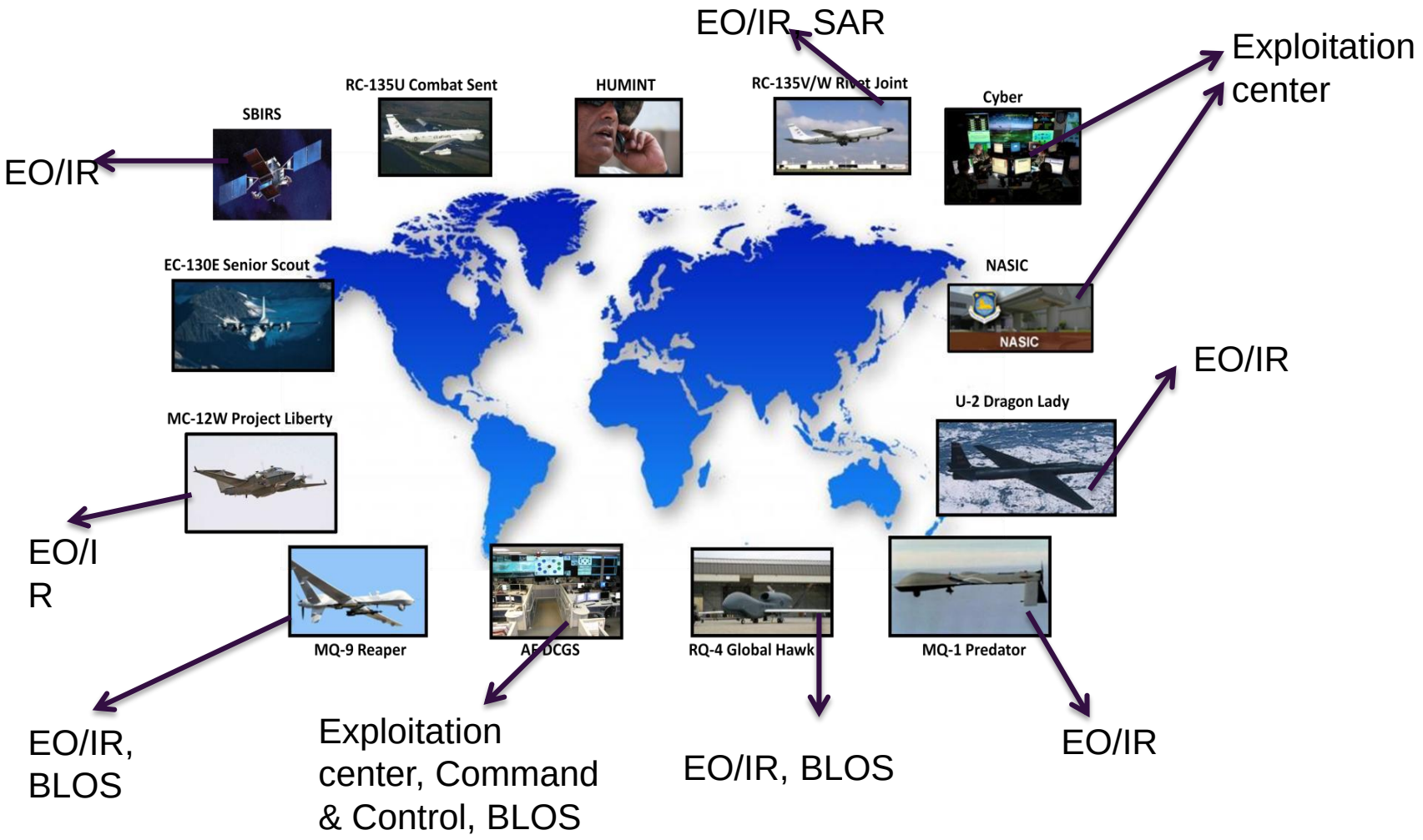
- Run SoS behavior model (Colored Petri Nets) for overall functionality and capability of the meta-architecture

FILA-SoS ISR Implementation

Initialize SoS

- Wave process: Understand the SoS objectives and operational concept (CONOPS), gather information on core systems to support desired capabilities
- FILA-SoS: Enter Input values required to run the FILA-SoS which include the number of negotiation cycles, meta-architecture generation model selection type and individual system negotiation model types
- The overall Capability: ISR & Targeting of Gulf War Scud TELs
- The sub capabilities (capabilities of contributing systems):
  - Electro-Optic/InfraRed (EO/IR) search capability
  - Side looking, synthetic aperture radar (SAR)
  - Command and control facilities
  - Exploitation centers (smaller ones in theater and a large one in CONUS)
  - Communication capabilities, both line of sight (LOS) limited to in-theater, and beyond line of sight (BLOS)

ISR Domain Model Detail



FILA-SoS ISR Implementation

Conduct_SoS_Analysis: Wave process: Establish an initial SoS baseline architecture for SoS engineering based on SoS requirements space, performance measures, and relevant planning elements. Execute the meta-architecture generation model which selects an initial SoS baseline architecture using the given input data. The key performance attributes are given below:

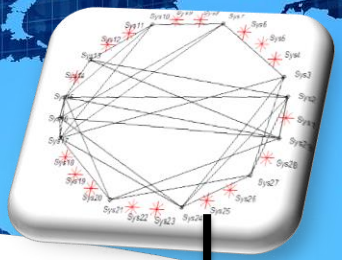
- **Performance**: Systems bring coverage sq/mi that are summed to provide SoS Performance
- **Affordability**: There are costs to develop interoperability, and costs to operate the systems. These both are summed to create the inverse of Affordability
- **Robustness**: We define the robustness as being greater if a smaller loss in performance results for the loss of any single cooperating system and its interfaces from the SoS architecture instance.
- **Flexibility:** Attribute describes the number of choices available to the SoS manager. The evaluation of Flexibility consists simply of counting the capabilities that have less than two sources.

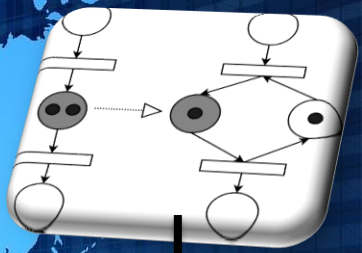
System	Type Sub-System	Cap ability Number	Coverage sq mi/hr;	Develop $M/ epoch/ interface	Operate $K/hr per system	Time to Develop, Epochs	Number possible in SoS	System Number
Fighter	EO/IR	1	500	0.2	10	1	3	1-3
RPA	EO/IR	1	2000	2	2	1	4	4-7
U-2	EO/IR	1	50000	0	15	0	1	8
DSP	IR	1	100000*.01	1	1	1	1	9
Fighter	Radar	2	3000	0.7	10	1	3	10-12
JSTARS	Radar	2	10000	0.1	18	1	1	13
Theatre	Exploit	4	5000	2	10	1	2	14-15
CONUS	Exploit	4	25000	0.2	0	0	1	16
Control Station/ AOC	Cmd & Control	5	1	1	2	1	2	17-18
LOS Link	Comm	3	1	0.2	0	1	2	19-20
BLOS Link	Comm	3	1	0.5	3	1	2	21-22

FILA-SoS

SoS Acquisition Manager

SoS Acquisition Environment





SoS

Initialize SoS

Meta architecture generated

Conduct SoS Analysis

SoS Architecture

Executable Models

Bi-Lateral Negotiation on Multiple Issues

Develop/Evolve SoS

Object Process Methodology

Colored Petri Nets

Opportunistic model

Selfish Model

Cooperative Model

Plan SoS Update

Architecture Assessment model

System Behavior Types

Implement SoS Architecture

Independent Modules In FILA-SoS

1. Meta-Architecture Generation Fuzzy Genetic model—MATLAB code
2. Meta-Architecture Generation Multi-Level model—MATLAB code
3. Architecture Assessment--- MATLAB code
4. SoS Negotiation Model- JAVA code
5. System Negotiation Model: Selfish – MATLAB code
6. System Negotiation Model: Cooperative –MATLAB code
7. System Negotiation Model: Opportunistic-MATLAB code
8. Executable Model--- OPM & CPN
9. Overall Negotiation Framework – JAVA code

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FILA-SoS: Flexible Intelligent Learning Architectures for SoS

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FILA-SoS Capabilities

- Integrated model for modeling and simulating SoS systems with evolution for multiple waves.
- Models can be run independently and in conjunction with each other
- Two model types represent SoS behavior and various individual system behavior
- Study of negotiation dynamics between SoS and individual systems

FILA-SoS "What-if" Analysis; Model Modularity

- Variables such as SoS funding and capability priority can be changed as the acquisition progresses though wave cycles
- Simulation of any architecture through colored petri nets.
- Simulate rules of engagement & behavior settings: all systems are selfish, all systems are opportunistic, all systems are cooperative or a combination

FILA-SoS Value

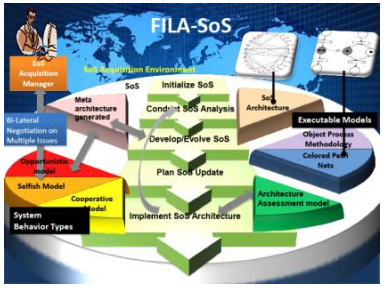
- Aiding the SoS manager in future decision making
- Understand emergent behavior of systems in the acquisition environment and impact on SoS architecture quality
- Study the dynamic behavior of different type of systems (selfish, opportunistic, cooperative)
- Identify intra and interdependencies among SoS elements and the acquisition environment

Potential Application

- Can be use to model of wide variety of complex systems models such as logistics, cyber-physical systems etc.
- Test-bed for decision makers to evaluate operational guidelines and principles for managing various acquisition environment scenarios
- Applicable to SoS that evolve as it has the multiple wave simulation capability

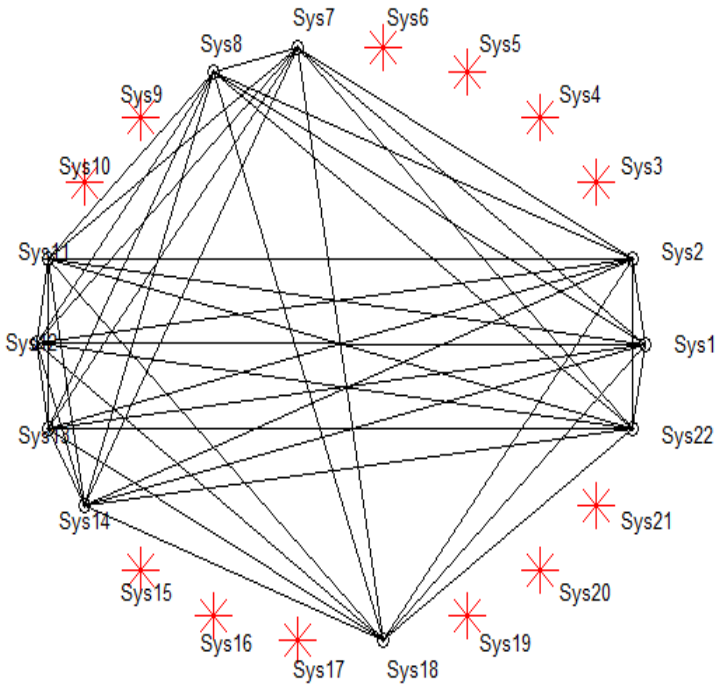
Possible Future Capabilities

- Extending the model to include multiple interface alternatives among systems
- Incorporation of risk models into environmental scenarios



Searching for SoS Meta-Architecture

(Multi-level Optimization)



Architecture I

Systems Selected
Fighters (EO/IR) (1-2)
RPA (7)
U-2 (8)
Fighters (Radars-11,12)
JSTARS (13)
THEATRE (14)
Control Station/ AOC (18)
BLOS Link(19,20)

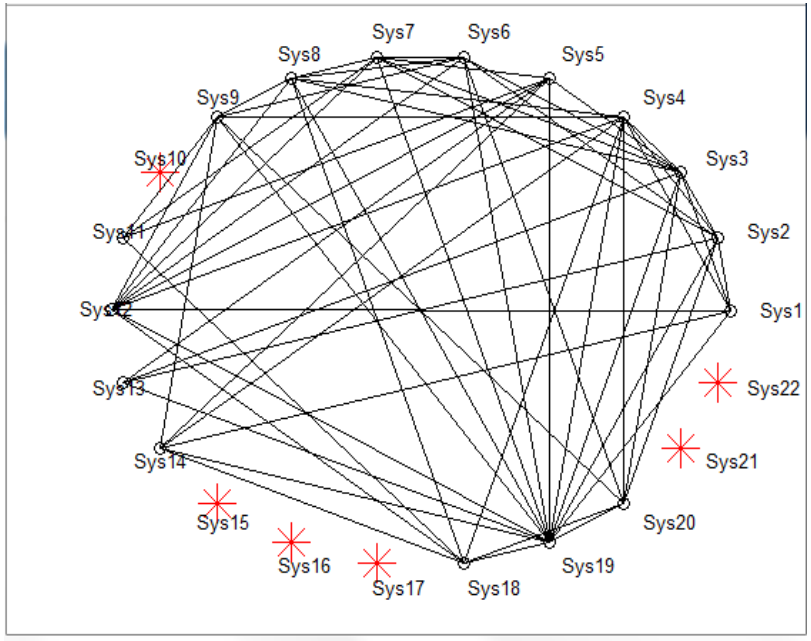
Interfaces Selected	
Fighters (EO/IR)	Fighters (Radar)
Fighters (EO/IR)	U-2
Fighters (EO/IR)	JSTARS
U-2	JSTARS
THEATRE	U-2
Control Station/ AOC	BLOS Link
…	…

Fighters (EO/IR)	**Fighters (EO/IR)**	**…**	**…**	**BLOS**	**$I_{\text{Fighters with JSTARS}}$**	**$I_{\text{Fighters with U-2}}$**	**$I_{\text{JSTARS with U-2}}$**
Systems					Interfaces		

X_1	X_2	X_i	…	X_m	$X_{1 \text{ with } 2}$	$X_{1 \text{ with } 3}$	$X_{1 \text{ with } m}$	$X_{2 \text{ with } 3}$	…	$X_{i \text{ with } j}$	…	$X_{(m-1) \text{ with } m}$
Systems					Interfaces							

Searching for SoS Meta-Architecture

(Fuzzy genetic Optimization)



Architecture II

Systems Selected
Fighters (EO/IR) (1,2,3)
RPA (4,5,6,7)
U-2 (8)
DSP(9)
Fighters (Radars-11,12)
JSTARS (13)
THEATRE (14)
Control Station/ AOC (18)
BLOS Link(22)

Interfaces Selected	
Fighters (EO/IR)	Fighters (Radar)
Fighters (EO/IR)	U-2
Fighters (EO/IR)	JSTARS
U-2	JSTARS
THEATRE	U-2
Control Station/ AOC	BLOS Link
…	…

Fighters (EO/IR)	**Fighters (EO/IR)**	**…**	**…**	**BLOS**	**$I_{\text{Fighters with JSTARS}}$**	**$I_{\text{Fighters with U-2}}$**	**$I_{\text{JSTARS with U-2}}$**
Systems					Interfaces		

X_1	X_2	X_i	…	X_m	$X_{1 \text{ with } 2}$	$X_{1 \text{ with } 3}$	$X_{1 \text{ with } m}$	$X_{2 \text{ with } 3}$	…	$X_{i \text{ with } j}$	…	$X_{(m-1) \text{ with } m}$
Systems					Interfaces							

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SoS Architecture Assessment Model

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Engineering Management and Systems Engineering Department

Model Capabilities

- Capture non-linearity in key performance attribute tradeoffs
- Can accommodate any number of attributes for a selected SoS capability
- Capture multiple stakeholder's understanding of key performance attributes
- Algorithms to determine the value of the attributes
- Evaluate the quality of a given architecture based on the value of the attributes

What-if Analysis; Model Modularity

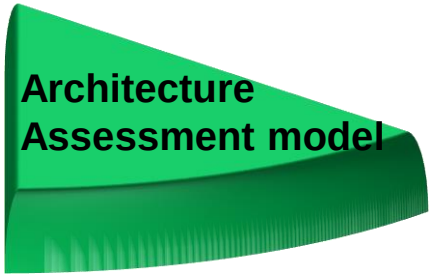
- Attribute definitions and algorithms are easily changed based on domain
- Model can be adjusted for different domains and stakeholder's
- New attributes can be added and old ones discarded
- Relative priorities of the attributes can also be accommodated by prioritizing assessment rules

Model Value

- By exploring the architecture 'space' with the "What-if" analysis, the stakeholders can develop a better understanding of how component systems can fit and work together
- Provide more realistic assessment than utility functions

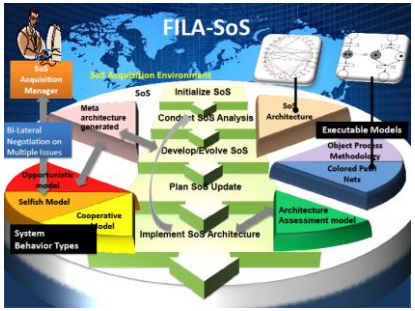
Potential Application

- Discovering, exploring, and adjusting stakeholder's firmly held (and sometimes mistaken) beliefs
- Finding new ways for systems to work together
- Finding more cost effective SoS arrangements
- Aid in negotiations with component systems to build an SoS



Possible Future Capabilities

- Improved visualization of the impact of many variables in SoS architecture and design
- Automated adjustment of model parameters



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Fuzzy-Genetic Optimization Model

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Model Capabilities

- Evolutionary multi-objective optimization model for SoS architecting with many key performance attributes (KPA)
- Involves dynamic assessment of domain inputs
- Returns the best architecture consisting of systems and their interfaces

What-if Analysis; Model Modularity

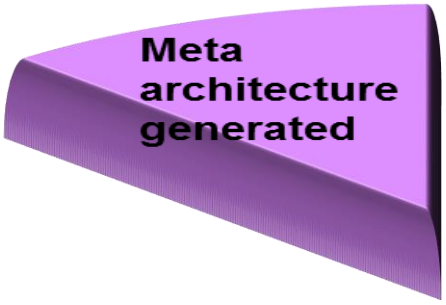
- What happens if selected attributes such as performance, cost, and deadline of the systems change
- Analyze the range of different KPA's over the set of architectures
- What happens if number of systems having net centric capability reduces

Model Value

- Adds to the existing meta-architecture generation techniques
- Takes into account the net-centricity of the architecture
- Returns a set of SoS to initiate negotiation
- Fuzzy Assessor for several competing objectives

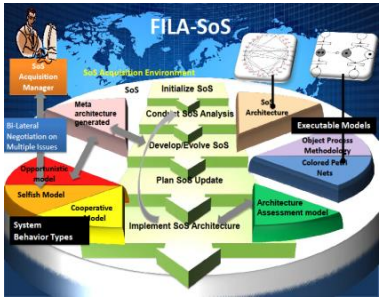
Potential Application

- Capable of finding architectures for multiple waves
- Model can be applied in any SoS domain such as logistics, network-centric systems, cyber-physical systems and supply chain



Possible Future Capabilities

- Add multiple interfaces among a set of systems e.g. energy flow, information, and mechanical
- Estimation of Component and Interface Complexity
- Modify the model for a specific potential application



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Multi-Level Optimization Model

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Model Capabilities

- Generic mathematical model for SoS architecting with multiple attributes such as:
  - Min cost, Max performance, Min deadline
- Efficient evolutionary algorithm for solutions
- Returns a set of SoS alternatives

What-if Analysis; Model Modularity

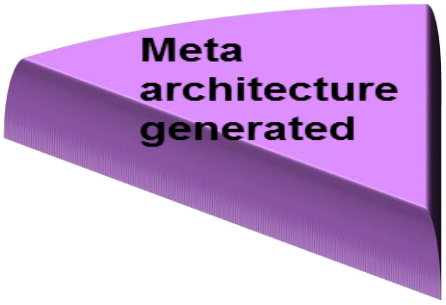
- What happens if selected attributes such as performance, cost, and deadline of the systems change
- What happens if some of the systems are not available or they cannot provide some of the capabilities they could provide
- What happens if systems can provide additional capabilities

Model Value

- Models practical settings of SoS architecting
  - Fund allocation for improvement
- Considers different objectives for SoS architecting
- Returns a set of SoS to initiate negotiation

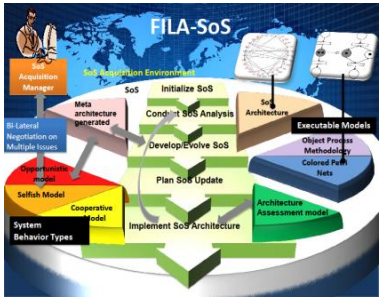
Potential Application

- Initiating the negotiation process
- Model can be applied in any SoS domain such as logistics, network-centric systems, cyber-physical systems and supply chain



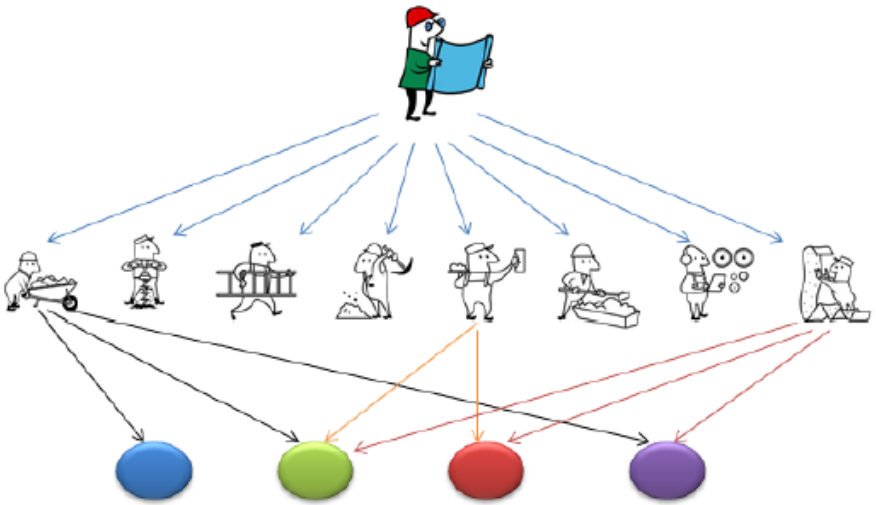
Possible Future Capabilities

- Modeling negotiation within SoS architecting
- Modeling competition among the systems
- Modeling flexibility of the systems and how to incentivize systems to become flexible
- Modify the model for a specific potential application



A System of Systems with Individual System Contracts

A Stackelberg Game



A Stackelberg Game:

- Leader: SoS Architect
  - Select the systems and allocate funds to the selected systems
- Followers: Selected systems
  - Improve the performance of the capabilities

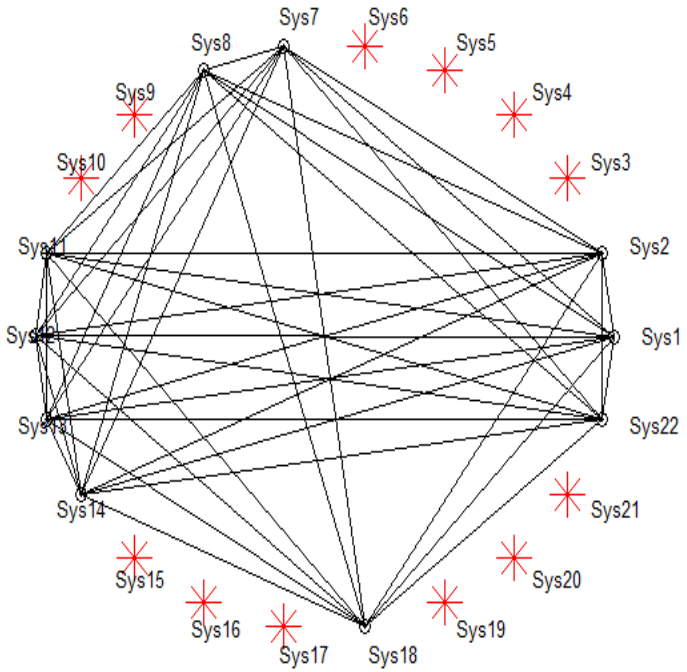
FILA-SoS ISR Implementation

•Develop/ Evolve SOS

- Wave process: Identify the necessary changes in contributing systems in terms of interfaces and functionality in order to implement the SoS architecture
- FILA-SoS: Send connectivity request to individual systems and start the negotiation between SoS and individual systems

Select Different System Behaviors

Systems Selected	Behavior
Fighters (EO/IR) (1-2)	Opportunistic, Opportunistic
RPA (7)	Opportunistic
U-2 (8)	Cooperative
Fighters (Radars-11,12)	Cooperative, Selfish
JSTARS (13)	Opportunistic
THEATRE (14)	Cooperative
Control Station/ AOC (18)	Selfish
BLOS Link(22)	Selfish



Architecture I

- ✓ **Assessment for the meta-architecture =3.69**
- ✓ **Key Performance Parameters values**
  - Performance=2.65 (More Acceptable)
  - Affordability=3.72
  - Flexibility=3
  - Robustness=3.76

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SoS Negotiation Models

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Model Capabilities

- Game theoretic negotiation model that will maximize the welfare for parties involved in the negotiation
- SoS utility function that takes into account local objectives for the individual systems as well as global SoS objective
- Incentive contract design to persuade uncooperative systems to join the SoS development

What-if Analysis; Model Modularity

- Analysis of incentive mechanisms under different behavioral settings including
  - When selfish behavior dominates the acquisition environment
  - When opportunistic behavior dominates
  - When cooperative behavior dominates
- Analysis of incentive mechanisms when there is uncertainty in individual system performance outcomes

Model Value

- Analysis of how incentives can be used to improve lack of collaboration in SoS acquisition which is a leading problem in SoS acquisition effectiveness.
- Analysis of how incentives can be used to ensure effective SoS mission performance

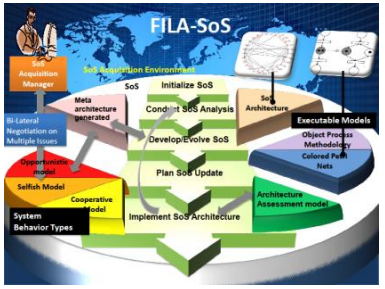
Potential Application

- Tool for evaluating operational guidelines and principles for incentive contract design for SoS acquisition under various acquisition environment scenarios

Bi-Lateral Negotiation on Multiple Issues

Possible Future Capabilities

- Study of risk taking preferences of individual systems and SoS manager and its impact on incentive contract design
- Incentive contract design for individual system groups that interact with each other



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Individual System Behavior Models: Non-Cooperative model (Selfish behavior)

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Model Capabilities

- A negotiation protocol that clearly defines how negotiations are initiated, continued, and terminated.
- A decision framework of contract negotiation for individual systems.
  - A model of individual system's participation capability and negotiation behavior.
  - A generator of negotiation alternatives in the presence of multiple conflicts.
  - Three optimization models that help search alternatives with a minimum impact of conflicts.
  - An conflicts evaluation model that estimates negotiation outcomes for each alternative.

What-if Analysis; Model Modularity

- What if an individual system is more/less capable than the SoS expects?
- What if an individual system is more/less cooperative than the SoS expects?
- What if an individual system is a strategic negotiator?
- Whether an individual system can be impacted by negotiation strategies of the SoS, such as monetary incentive, time pressure, and others; and how?

Model Value

- A negotiation model for individual systems in the setting of SoS acquisition, which can be used by the SoS manager to assess and train the SoS acquisition abilities/strategies.
- Realistic, challenging responses to the SoS manager's request for participation, which the SoS manager can use for developing an understanding of individual systems that have self-interests and are strategic negotiators, and also developing strategies for handling them.

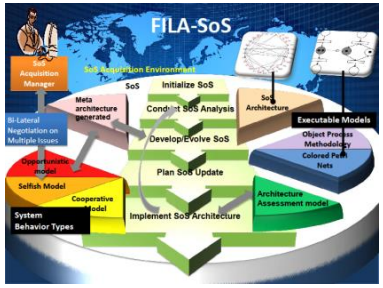
Potential Application

The negotiation model can be used by

- When changes in a system is difficult to make
- Individual suppliers/service providers in the negotiation of supply-procurement contracts.
- Individual persons in the development of dynamically reconfigurable teams.

Possible Future Capabilities

- An intelligent algorithm that can determine an optimal alternative in a fast manner.
- A learning mechanism with which the individual systems model can effectively calibrate the guess of SoS's utility functions.
- A broader band of negotiation strategies that can handle a wider range of negotiation scenarios.



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Individual System Behavior Models: Semi-Cooperative (opportunistic behavior)

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Model Capabilities

- Capability of being flexible or opportunistic: i.e., selfish or unselfish
- Markov-chain based model designed for handling uncertainty in negotiation modeling in an SoS

What-if Analysis; Model Modularity

- Testing scenarios for given performance criteria and given number of interacting systems in an SoS
- Ability to determine budget and schedule for any given negotiation model for an SoS

Model Value

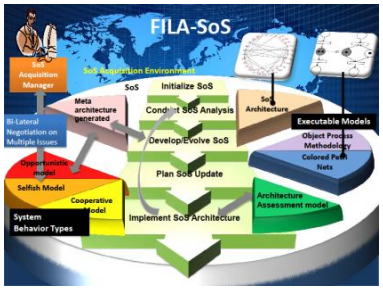
- Useful for testing opportunistic behavior prevalent in industry partners exhibiting risk-prone behavior
- Ability to model very selfish to very selfless behavior on a continuum using a numerical user-adjustable scale

Potential Application

- Modeling behavior of defense firms competing to obtain contract
- Modeling of project durations for any system within the SoS
- Changes in a system are reasonable to make

Possible Future Capabilities

- Testing for risk-prone behavior of systems within an SoS
- Implementation of Machine Learning models for SoS controller



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Individual System Behavior Models: Cooperative

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Model Capabilities

- The negotiation protocol is computationally scalable to a large number of issues and system types
- Presents a semi-cooperative behavior
- Can negotiate multiple issues simultaneously
- Illustrates the cognitive and financial aspects of human negotiations
- Bilateral negotiation mechanism

What-if Analysis; Model Modularity

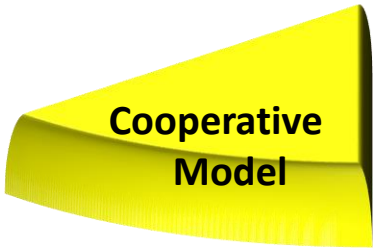
- The ability to work with other negotiation models
- Can work as an independent module
- The preferences and the strategy considerations of the systems are private, i.e., they are not known to the other systems or manager
- Can perform simulations for various scenarios
- Knowledge discovery and agent learning tools

Model Value

- Provide solutions in complex automated negotiation scenarios
- Model predictions can be used about similar situations which are previously not modeled
- Identify counterintuitive results or causal relationships

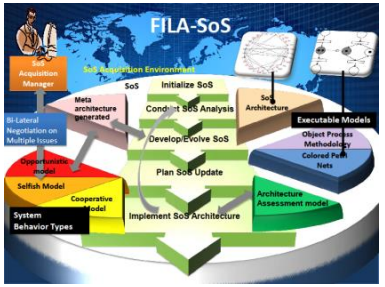
Potential Application

- Includes logistics, supply chain, cyber-physical systems, e-commerce, decision-making support etc.
- Changes in a system are easy to make



Possible Future Capabilities

- Solve the problem using a multi-criteria group decision making problem to handle multiple offers from the SoS manager
- Employ computing with words for decision making



Execute the negotiated Architecture through Object Process Methodology and Colored Petri Nets

SYSTEMS ENGINEERING Research Center

Missouri S&T Smart Engineering Systems Lab
Engineering Management and Systems Engineering Department

Model Capabilities

- Model the interactions between components of a system or subsystems in SOS
- Capture the dynamic aspect of the SoS and Simulate the behavior of the SoS
- Access various behavior related performance of the SoS
- Access different constitutions or configurations of the SoS

What-if Analysis; Model Modularity

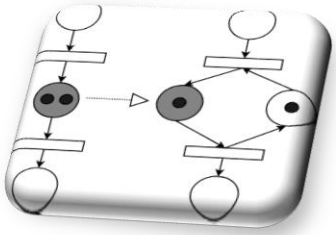
- Can be used in accessing the impact of changes in system parameters, constitution, and configuration to the overall functionality and capability of the SoS
- Can assess the system performance under various operational scenarios
- Good support of hierarchical modeling and can be used independently

Model Value

- Examine whether and how well the constituent systems can collaborate with each other in delivering the desired capabilities when the SoS is in operation
- Detailed, quantitative performance analysis

Potential Application

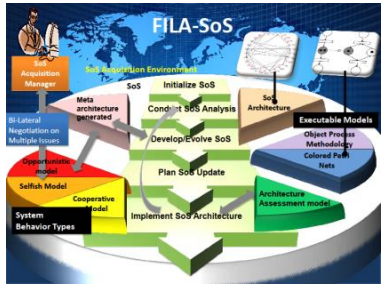
- Useful in situation where interactions between constituent systems, or system components are critical to fulfillment of the overall functionality and capability of the SoS
- Access the emergent behavior of the SoS



Executable Colored Petri Nets

Possible Future Capabilities

- Automate the model construction, alternative generation and performance analysis process.
- Examine all possible operational states of the SoS



SECOND WAVE

- **Plan SoS Update /**

- Wave process: Plan for the next SoS upgrade cycle based on the changes in external environment, SoS priorities, options and backlogs
- FILA-SoS: Determine which systems to include based on the negotiation outcomes and form a new SoS architecture

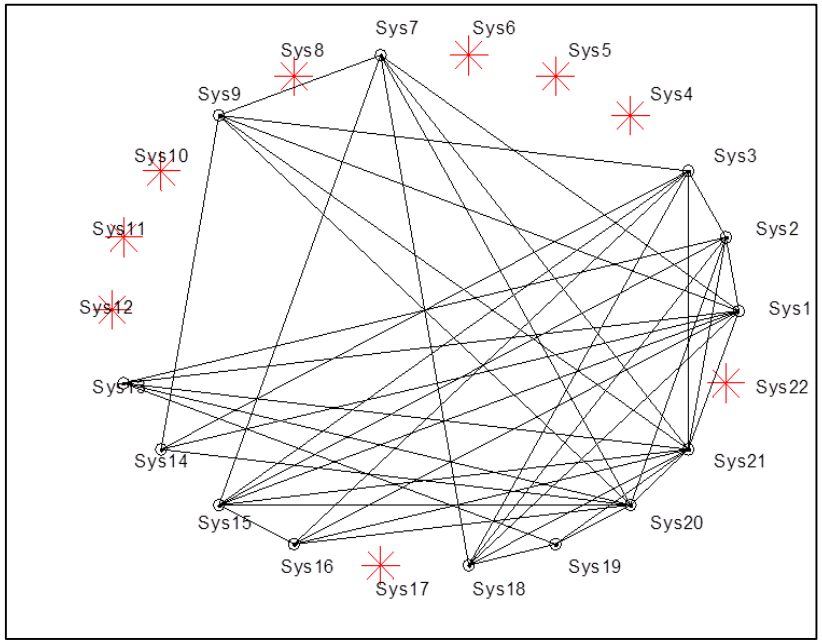
Evolution of SoS Architecture Through Multiple Waves

Sample Scenario for ISR-Wave 1 results

System	Type Sub-System	Cap ability Number	Coverage sq mi/hr;	Develop $M/ epoch/ interface	Operate $K/hr per system	Time to Develop, Epochs	System Number
Fighter	EO/IR	1	500	0.2	10	1	1
Trainer	EO/IR	1	2000	2	2	1	2-3
UAV	EO/IR	1	50000	0	15	0	4-8
DSP	IR	1	8000	0.1	1	1	9
Fighter	Radar	2	3000	0.7	10	1	10-12
JSTARS	Radar	2	10000	0.1	18	1	13
Theatre	Exploit	3	5000	2	10	1	14-15
CONUS	Exploit	3	25000	0.2	0	0	16
Control Station/ AOC	Cmd & Control	4	10000	1	2	1	17-18
LOS Link	Comm	5	10000	0.2	0	1	19-20
BLOS Link	Comm	5	5000	0.5	3	1	21-22

Evolution of SoS Architecture

- Meta-Architecture Wave 1



Assessment for the meta-architecture =3.47
Key Attribute values:

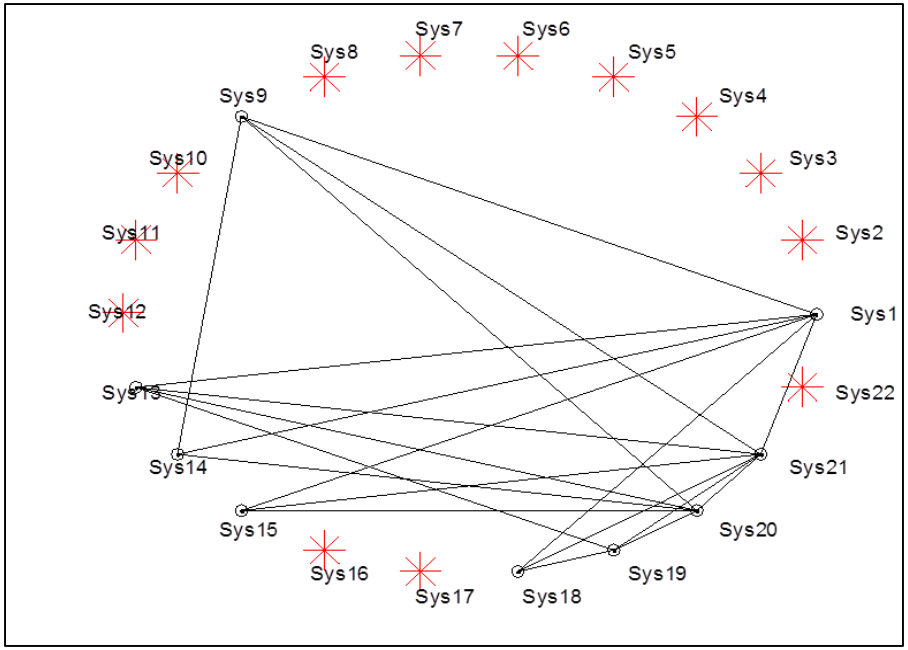
- Performance=2.16
- Flexibility=4
- Affordability=3.5
- Robustness=3.91

Systems selected in the Meta-Architecture

Systems Selected
Fighters (EO/IR) (1-3)
RPA (7)
U-2 (9)
JSTARS (13)
THEATRE (14,15)
CONUS (16)
Control Station/ AOC (18)
LOS link (19,20)
BLOS Link(21)

Evolution of SoS Architecture

- Negotiated Architecture Wave 1



Assessment for the meta-architecture =2.5
Key Attribute values:

- Performance=1.5
- Flexibility=2
- Affordability=3.72
- Robustness=2

Systems selected after negotiation S_i

Sys no	Behavior
9	selfish
13,14,15	cooperative
18	opportunistic
19	selfish
21	selfish
22	cooperative

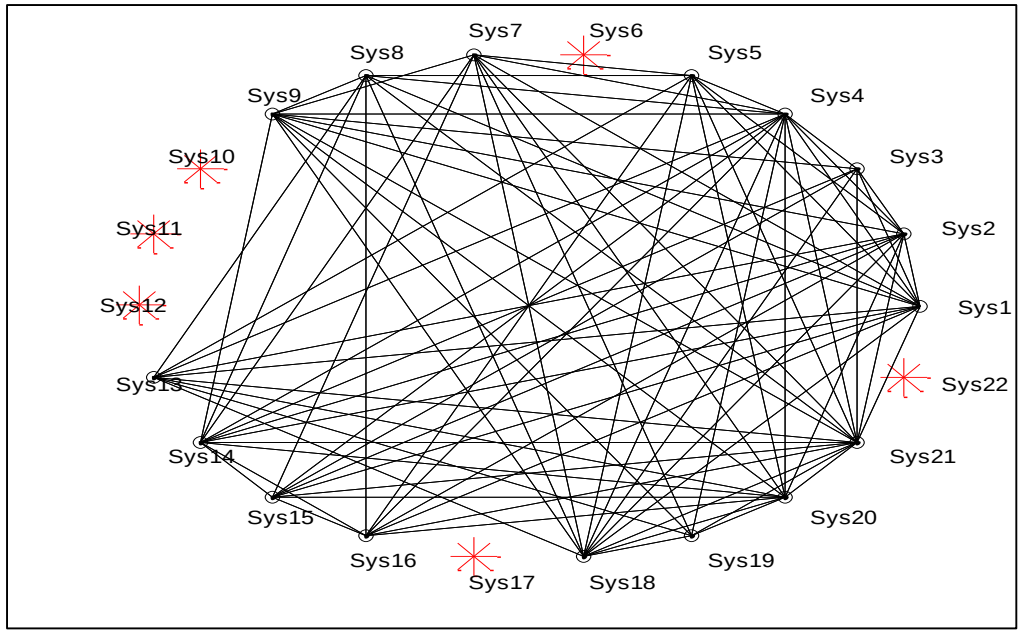
Evolution of SoS through to the Wave 2

- Input Domain File

System	Type Sub-System	Cap ability Number	Coverage sq mi/hr;	Develop $M/ epoch/ interface	Operate n///hr$K/hr per system	Time to Develop, Epochs	System Number
Fighter	EO/IR	1	500	0.2	10	1	1
Trainer	EO/IR	1	12000	0.1	8	1	2-3
UAV	EO/IR	1	8000	0.5	2.5	1	4-8
DSP	IR	1	8000	0.1	1	1	9
Blimp	Radar	2	20000	0.5	12	1	10-12
JSTARS	Radar	2	10000	0.1	18	1	13
Theatre	Exploit	3	5000	2	10	1	14-15
MOBExp	Exploit	3	15000	0.1	0.2	0	16
MOBC2	Exploit	4	12000	1	2	0	17
Control	Cmd &	4	10000	1	2	1	18
LOS Link	Comm	5	10000	0.2	0	1	19-20
BLOS Link	Comm	5	5000	0.5	3	0	21
Mil-Sat	Comm	5	15000	1	5	1	22

Evolution of SoS Architecture

- Meta-Architecture Wave 2



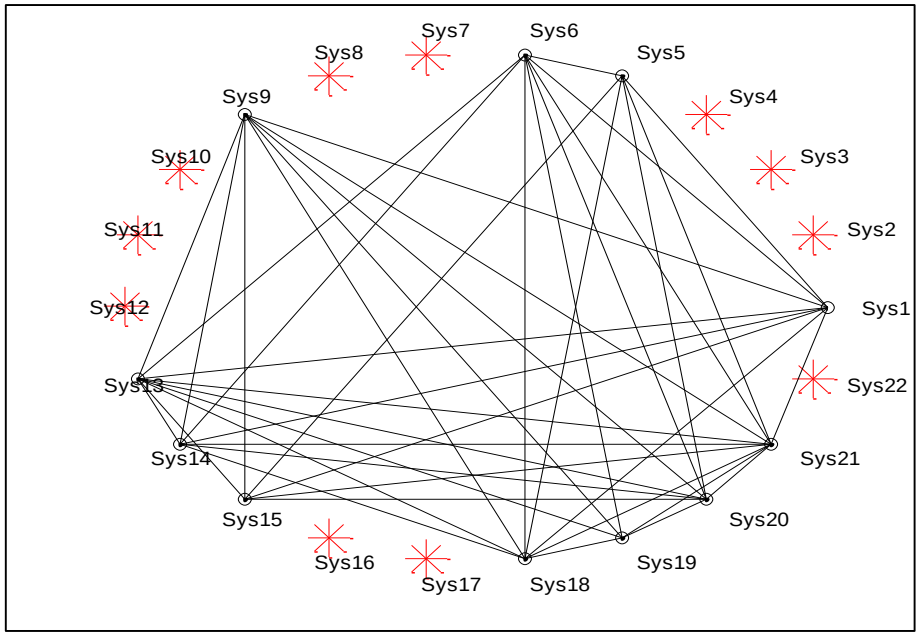
Assessment for the meta-architecture =3.61
Key Attribute values:

- Performance=2.28
- Flexibility=4
- Affordability=3.09
- Robustness=3.77

Systems Selected
Fighters (EO/IR) (1)
Trainer (2-3)
UAV (4,5,7,8)
DSP(9)
JSTARS (13)
THEATRE (14,15)
MOBExp(16)
Control Station/ AOC (18)
LOS link (19,20)
BLOS Link(21)

Evolution of SoS Architecture

- Negotiated Architecture Wave 2



Assessment for the meta-architecture =2.9
Key Attribute values:

- Performance=1.94
- Flexibility=2.7
- Affordability=3.6
- Robustness=3

Systems selected after negotiation S_i

Sys no	Behavior
1	selfish
5,6	opportunistic
9	selfish
13,14,15	cooperative
18	opportunistic
19,20,21	selfish

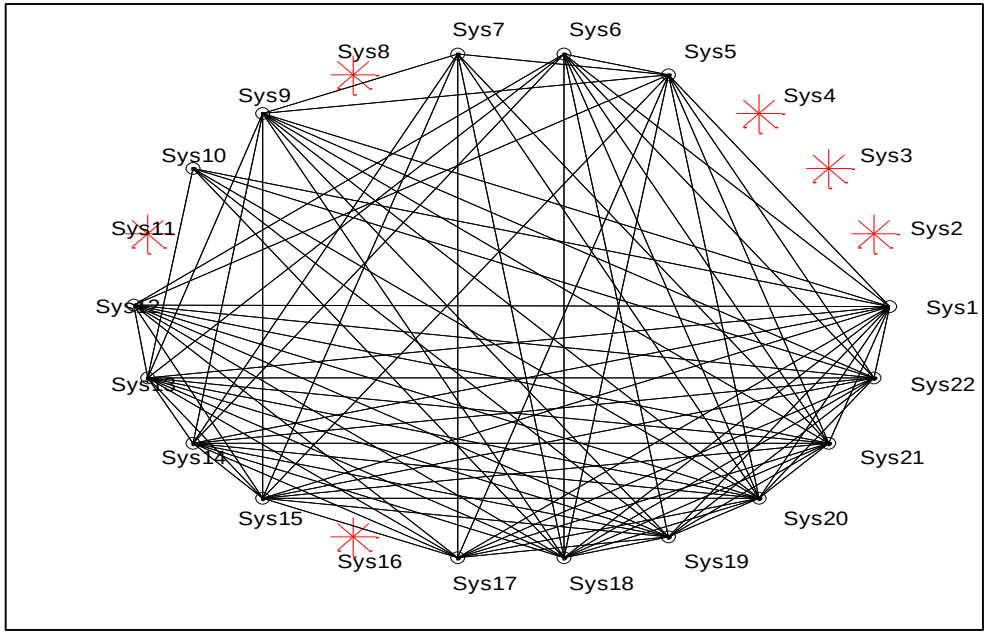
Evolution of SoS through to the Wave 3

Input Domain File

System	Type Sub-System	Cap ability Number	Coverage sq mi/hr;	Develop $M/ epoch/ interface	Operate n///hr$K/hr per system	Time to Develop, Epochs	System Number
Fighter	EO/IR	1	500	0.2	10	1	1
Trainer	EO/IR	1	4000	0.5	15	1	2-3
UAV -A	EO/IR	1	3000	1	12		
UAV-B	EO/IR	1	8000	0.5	2.5	1	5-6
UAV-C	EO/IR	1	5000	0	10	1	7-8
DSP	IR	1	8000	0.1	1	1	9
Blimp	Radar	2	30000	1.9	5	1	10-12
JSTARS	Radar	2	10000	0.1	12	1	13
Theatre	Exploit	3	5000	2	10	1	14-15
MOBExp	Exploit	3	4000	0.15	1	0	16
MOBC2	Exploit	4	4000	0.1	0.2	0	17
Control	Exploit	4	12000	1	2	1	18
LOS Link	Cmd &	5	10000	0.2	0	1	19-20
BLOS Link	Comm	5	5000	0.5	3	1	21
Mil-Sat	Comm	5	6000	1	1	0	22

Evolution of SoS Architecture

- Meta-Architecture Wave 3



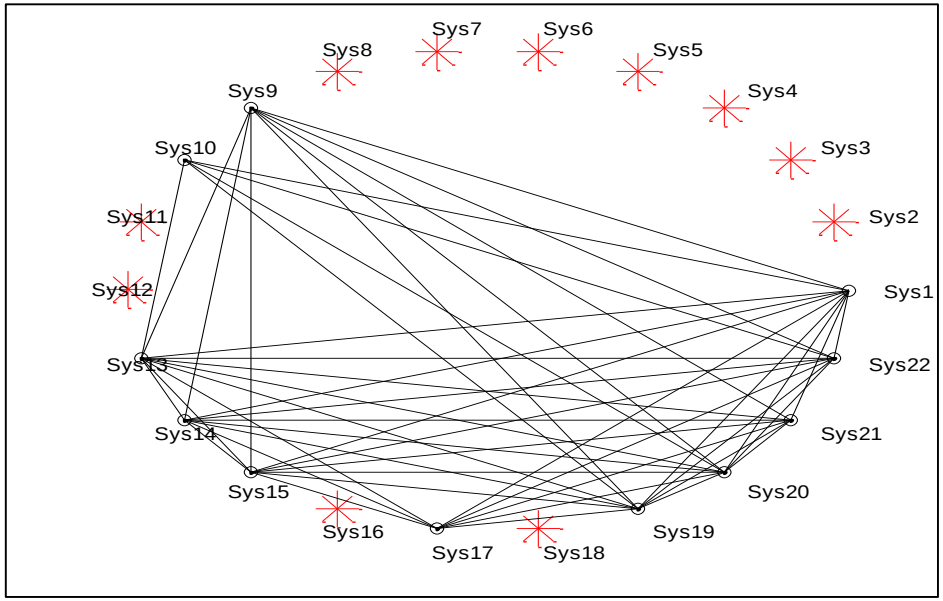
Assessment for the meta-architecture =3.59
Key Attribute values:

- Performance=2.23
- Flexibility=4
- Affordability=2.69
- Robustness=4

Systems Selected
Fighters (EO/IR) (1)
UAV-B (5,6)
UAV –C (7)
DSP(9)
Blimp (10)
JSTARS (13)
THEATRE (14,15)
MOBC2(17)
Control Station/ AOC (18)
LOS link (19,20)
BLOS Link(21)
Mil-Sat (22)

Evolution of SoS Architecture

- Negotiated Architecture Wave 3



Assessment for the meta-architecture =2.5
Key Attribute values:

- Performance=1.78
- Flexibility=2
- Affordability=3.27
- Robustness=1.29

Systems selected after negotiation S_i

Sys no	Behavior
1	selfish
9	selfish
10	opportunistic
13,14,15	cooperative
17	cooperative
19,20,21	selfish
22	cooperative

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